5.5 TRANSITION RADIATION DETECTOR (TRD) AND ASSOCIATED GAS SYSTEM

The role of the TRD (Figure 5.5.1-1) is to discriminate between electrons/anti-protons (e^-/p^-) and positrons/protons (e^+/p^+) over the Energy (E) range E = 3 – 300 GeV. This is accomplished by detecting X-ray photons emitted by electrons and positrons when they pass through a radiator. Heavier particles do not emit such radiation. The radiation is detected in tubes filled with Xe and CO_2 gas in an 80:20 ratio. Xenon gas ionizes very easily and is thus very sensitive to the passage of photons.

5.5.1 TRD Structure

The TRD detector is composed of 5248 proportional tubes which are made from a multi-layer wound composite structure. The composite includes layers of polyurethane, carbon-polyimide, aluminum, and Kapton (Figure 5.5.1-2). The straw tubes are grouped into 41 separate segments which are connected through gas manifolds. The straws have an inner diameter of 0.24 inch (6.02 mm), a wall thickness of 0.003 inches (72 microns), and vary in length from 31.5 inches (0.8m) to 78.7 inches (2.0m).

A straw module (Figure 5.5.1-3) consists of 16 straws glued together with 6 stiffeners running alongside the straws. Every 3.94 inches (10 cm), additional stiffeners are glued across the module for extra rigidity. The straw ends are glued into polycarbonate endpieces. The endpieces contain the wire fixation pieces (wire: gold plated tungsten, 0.001 inch (30 microns) diameter; wire fixation pieces (Cu/Te alloy), the gas distributor, and the gas seal.

The TRD is constructed from 20 layers of the straw modules where a gap of 0.91 inch (23 mm) between the layers is filled with a radiator material (polypropylene fleece). The upper 4 layers (72 modules) and the lower 4 layers (56 modules) are oriented in the X-direction and the 12 middle layers (200 modules) in the Y-direction (Figures 5.5.1-4 and 5.5.1-5).

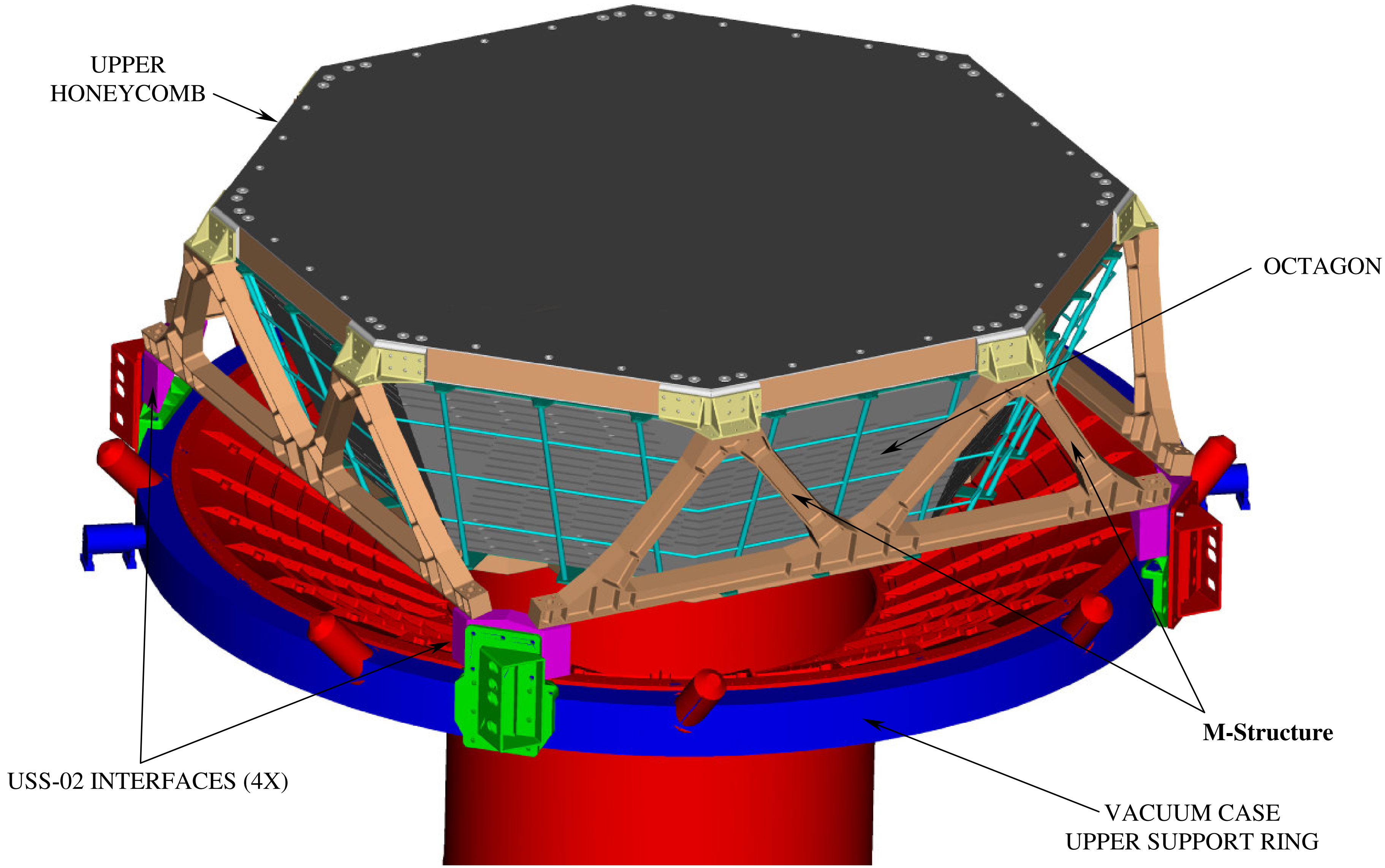

Figure 5.5.1-1 TRD Structure

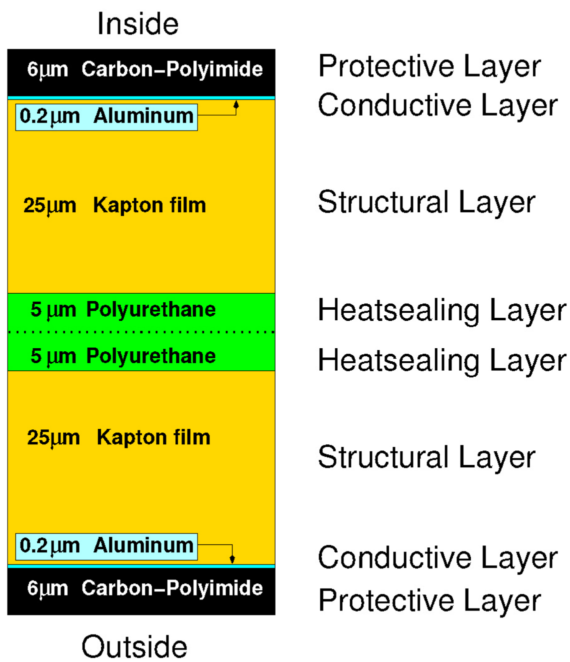

Figure 5.5.1-2 Composition of Straw Wall

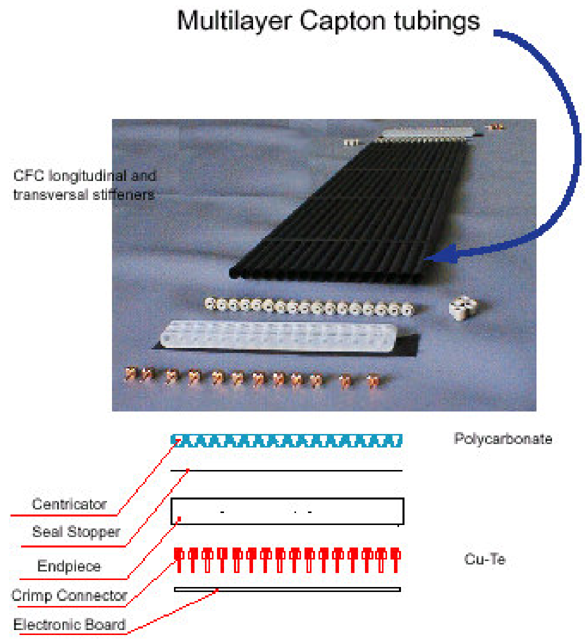

Figure 5.5.1-3 Straw Module Production

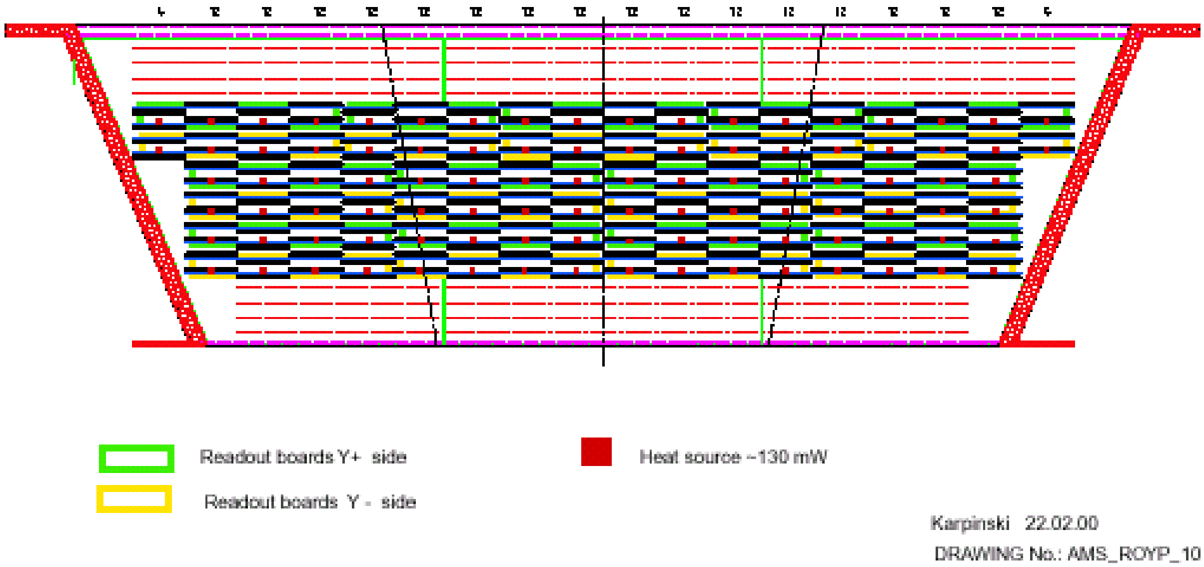

Figure 5.5.1-4 TRD X-Z Cross Section

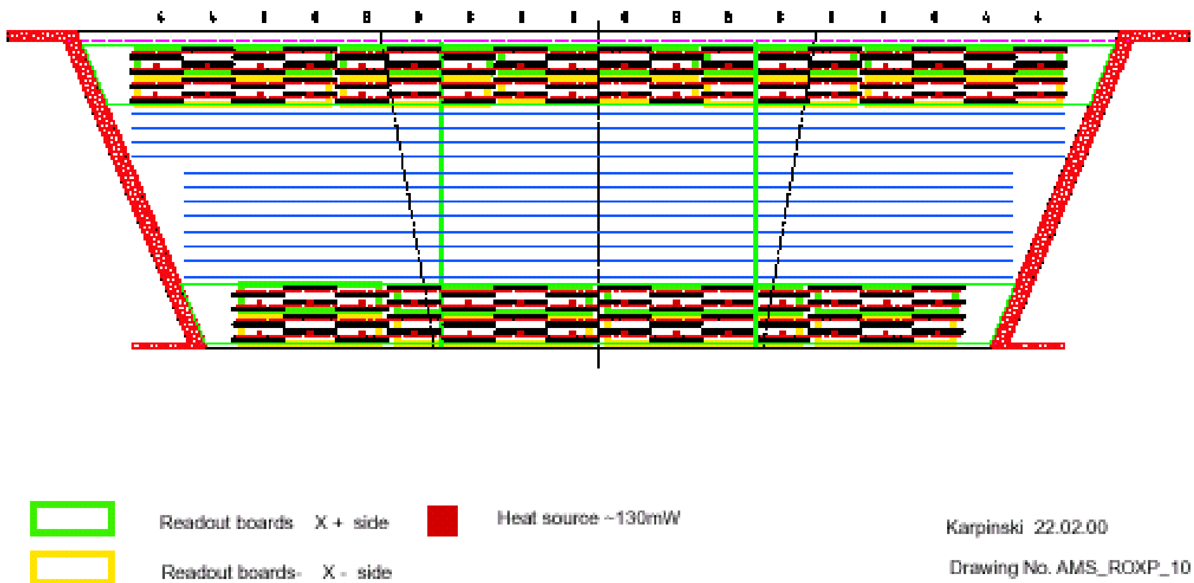

Figure 5.5.1-5 TRD Y-Z Cross Section

The 20 layers of straw modules and radiators are mounted in an octagon structure which consists of 8 honeycomb side panels [1.18 inches (30 mm) thickness], a lower honeycomb support plate, and an upper honeycomb plate. The size of the octagon structure is 91 inches x 24.5 inches (height) (2.3 m x 0.6 m). The combined weight of the TRD is 728 lbs (303.4 Kg). Inside the octagon structure, the straw modules are further supported by 4 bulkheads (0.1 inch (3 mm) thick), 2 in the Y-direction and 2 times 2 smaller ones in the X-direction (Figure 5.5.1-6).

The TRD is located at the top of the experiment stack above the Upper TOF. The Octagon Structure is supported by the M-Structure, which is mounted to the USS-02 at 4 locations, just above the vacuum case interface. The TRD corner joints are hard-mounted to the corner joints on the upper USS-02 (Figure 5.5.1-1).

The front-end readout electronics and the High Voltage (HV) distribution boards are mounted on special boards close to the module end pieces. The gas distribution system is also mounted close to the ends of the modules on the opposite side of the electronics.

Figure 5.5.1-6 TRD Bulkheads Inside the Octagon (Full Scale TRD Mockup)

5.5.2 TRD Gas Supply System

The TRD Gas Supply System supplies a mixture of 80% Xenon (Xe) and 20% Carbon Dioxide (CO_2). The density and purity of the gas mixture is monitored and adjusted to ensure efficient photon detection. The gas supply system includes three tanks, one for the Xe, one for the CO_2, and one mixing tank (Figures 5.5.2-1 and 5.5.2-2). These tanks are mounted to a support bracket and covered by shields to protect them from orbital debris. The support bracket is mounted to the wake side of the USS-02 (Figure 5.5.2-3), which also helps protect them from debris.

The Xe tank is a composite over-wrapped stainless steel tank that is designed and built by Arde, Inc. This tank is the same design as one that is used on the Plasma Contactor Unit for ISS. It has a maximum design pressure (MDP) of 3000 psid with a minimum temperature rating of –60°F and a maximum temperature rating of 150°F. The tank was designed with a minimum proof test factor of 1.5 x MDP and a minimum burst factor of 3.1 x MDP. It has an outside diameter of 15.4 inches (390 mm) and a volume of 1680 cubic inches (27.5 liters). It carries 109 lbs (49 Kg) of Xe at launch and has been tested to 8.9 G_{rms} at 0.08 g^2/Hz.

The CO_2 tank is also a composite over-wrapped stainless steel tank designed and built by Arde, Inc. This tank was designed for use on the X-33 vehicle and also has a maximum design pressure of 3000 psid with a minimum operating temperature of –100°F and a maximum operating temperature of 300°F. The tank is designed with a proof test factor of 1.6 x MDP and a minimum burst factor of 2.1 x MDP. The outside diameter is 12.4 inches (315 mm) and it has a volume of 813 cubic inches (13.3 liters). The tank weighs 9.5 lbs (20.9 kg) and it can hold a maximum of 11 lbs (5.0 kg) of CO_2. A vibration test has been performed to 8.9 G_{rms} at 0.07 g^2/Hz axially and 4.5 G_{rms} at 0.02 g^2/Hz laterally.

The small mixing tank will also be manufactured by Arde, Inc. It will have a nominal operating pressure of 200 psia, a normal operating temperature of 77°F and an MDP of 300 psid established by dual pressure relief devices and the source gas supply control. A proof test factor of 2.0 x MDP and a minimum burst factor of 4,0 x MDP will be used. The volume will be 61 cubic inches (1 liter).

The fittings and connections in the gas system include stainless steel tubing, welded joints, and numerous gas manifolds. The stainless steel tubing will range from 0.06 - 0.25 inch (1.6 - 6 mm) outer diameter. Connections will be made with welded joints (as an alternate, metal sealed fitting could be used). The connections between the gas manifolds and the TRD segments are made with 0.04 inch (1 mm) inner diameter stainless steel tubing and metal connectors.

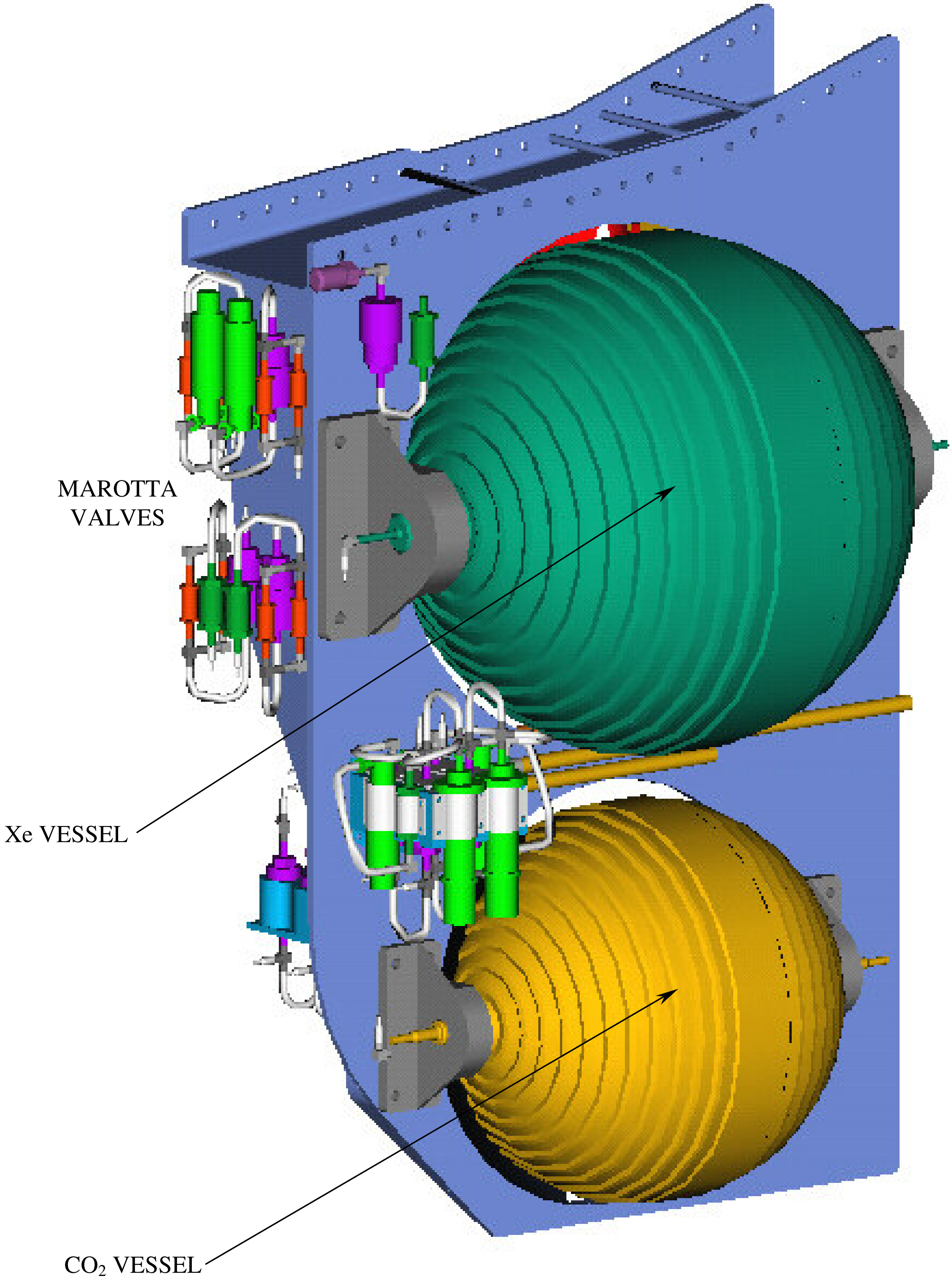

Figure 5.5.2-1 TRD Gas Supply System (Box S and Box C)

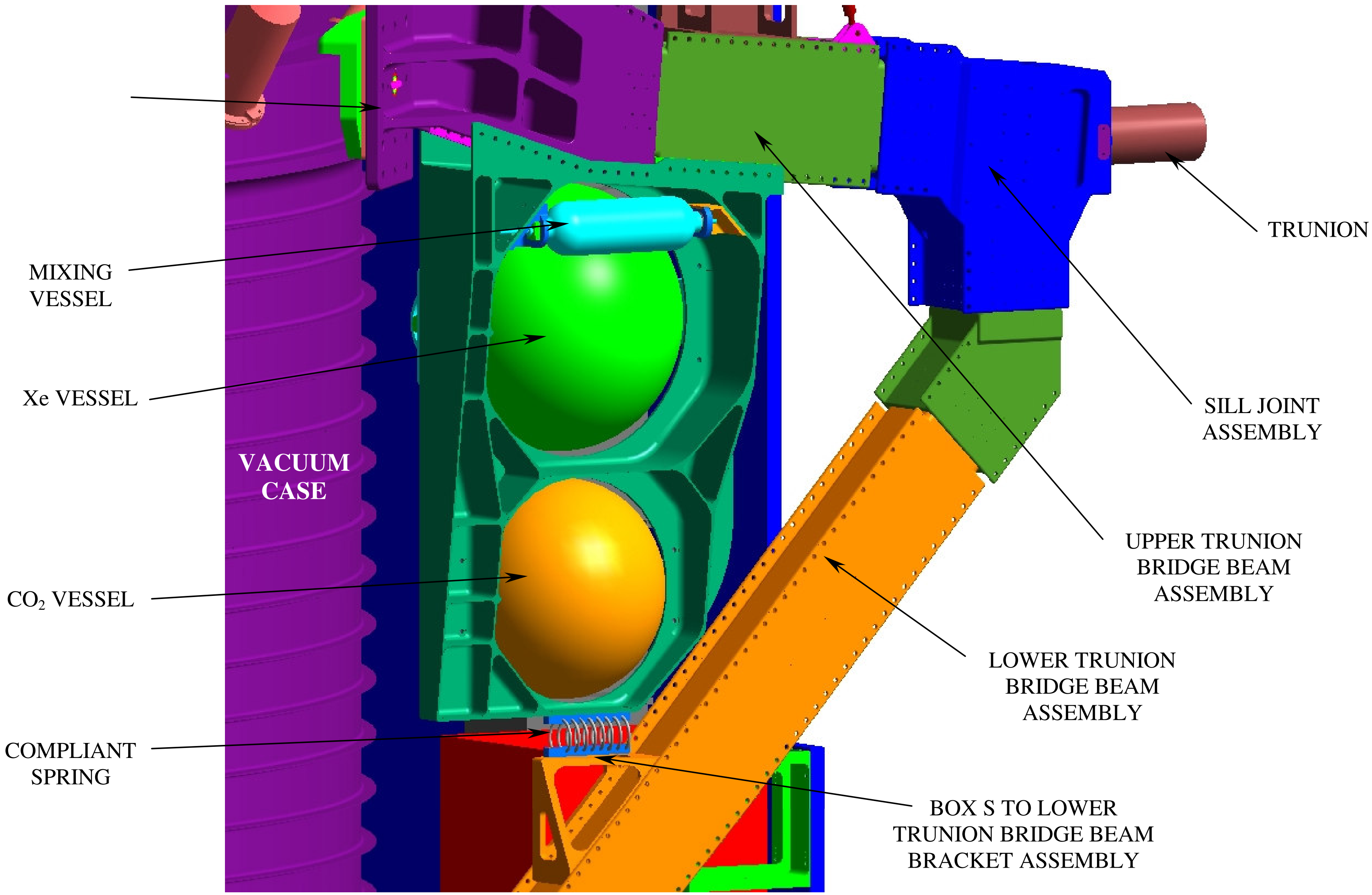

Figure 5.5.2-2 TRD Gas Supply System (Box S and Box C) on the Upper USS-02 Structure (Wake Side – Port)

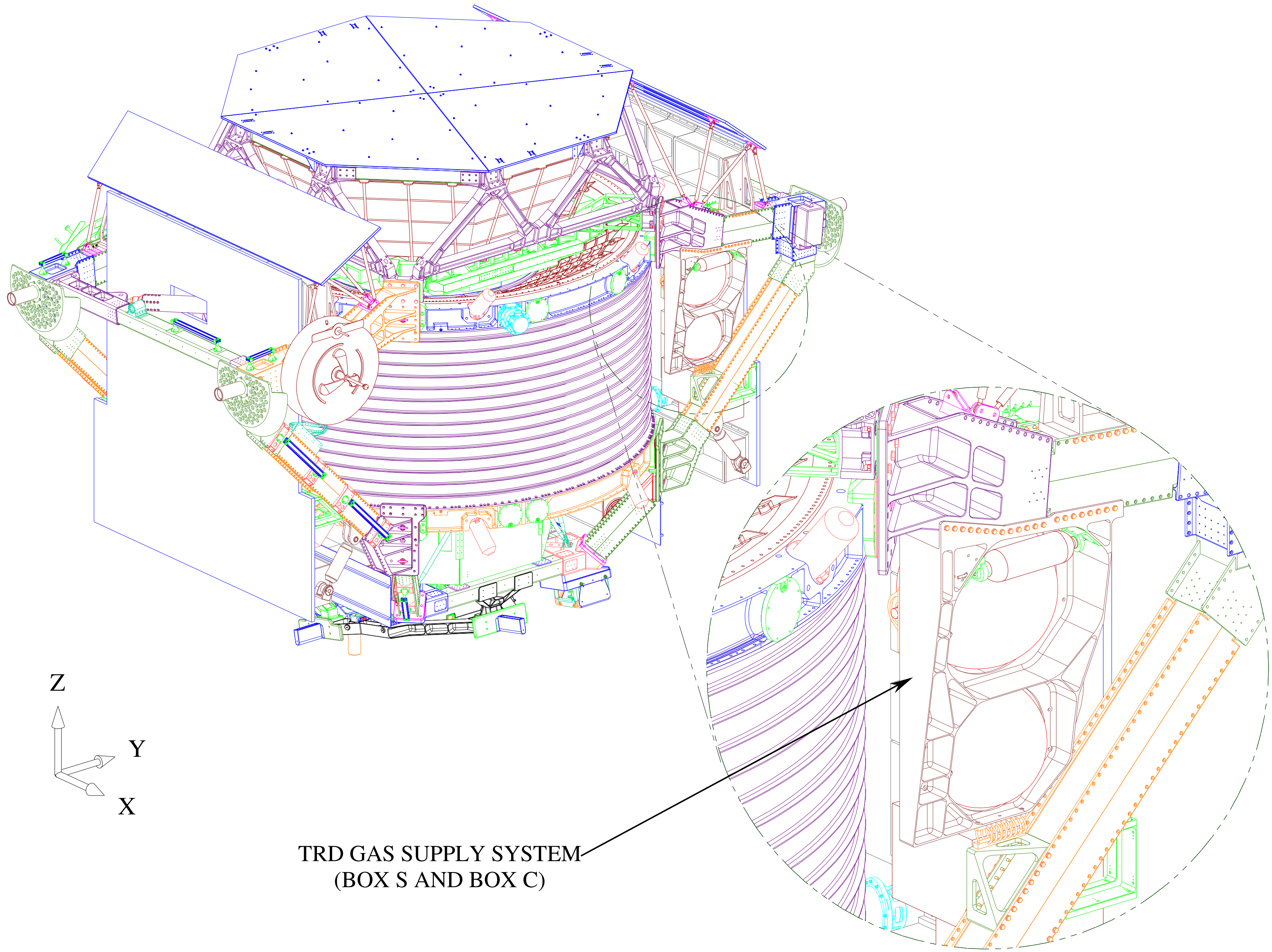

Figure 5.5.2-3 TRD Gas Supply System Mounted to the USS

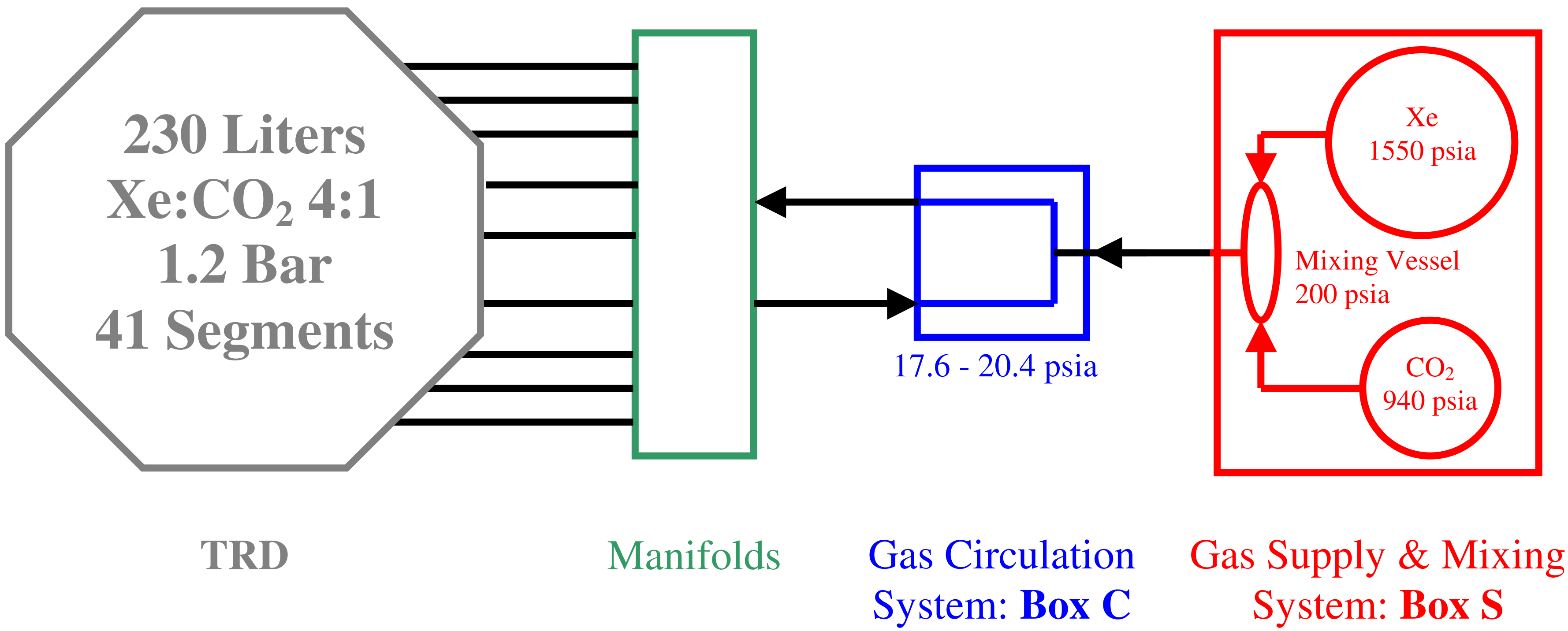

Figure 5.5.2-4 Schematic of the TRD Gas System [All pressures are at 77° F (25° C)]

The TRD straw tubes have a maximum design pressure of 29.4 psid. The minimum design temperature is –4°F and maximum design temperature is 95°F. Additional thermal/vacuum testing is planned to further refine these numbers. The relief valves will be set to 30 psia. The normal operating pressure is 14.7 to 20.4 psid on-orbit and 20.4 psid on the ground. The proof test factor of 1.5 x MDP will be employed and a minimum burst factor > or = 2.0 x MDP will be employed. Each of the 41 separate segments contains 244 – 427 in^3 (4 – 7 liters) of gas, for a total gas volume of 8.1 ft^3 (0.23 m^3). The nonflammable gas mixture is circulated through these tubes in a continuous loop. The density and purity of the gas mixture is monitored and corrected.

The 41 TRD segments are connected through manifolds to Box C, containing controls, monitors, and recirculation pumps. Box S provides Box C with pre-mixed gas from the gas supplies in a limited transfer volume (approximately 1 liter). A feed control between Boxes S and C is activated by computer approximately once a day. The general layout is shown in Figure 5.5.2-4. The 41 sealed TRD segments of approximately 342 in^3. (5.6 liters) each are held at 17.4 psi. Box C has an estimated volume of 150 in^3, held below 29 psi by relief valves. Mounted inside the Gas Supply System Box C are 4 calibration tubes (Reference Figure 5.5.4-1), which monitor the gas gain changes of the circulating mixture. The calibration tubes have an inside diameter of 0.24 inch (6 mm) like the straw tubes; however, they are mounted inside a stainless steel container (Figure 5.5.6-3). On the inner wall is a 0.2 microCurie (estimated 0.17 microCuries at time of launch, ~0.27-0.3 microCuries at loading) deposit of Fe^{55}. The 0.04 inch (1 mm) wall attenuates the 5.9 KeV radiation to a level less than detectable. The outer stainless steel container seals in the radiation again and supplies the gas for calibration.

5.5.3 Box S Description

Box S, shown in Figure 5.5.3-1, contains the gas reserves for the TRD. Gas is released from the two reservoirs into the mixing vessel (D), where it is combined in the required ratio and stored until such time as the straw tubes need to be refilled. Once needed, the combined gas is transferred to Box C for circulation.

The straw tubes are projected to lose approximately 0.25 liters of gas per day. At that rate, the mixing operation should take place once per day. For Xenon, valve V1a is opened for 100 μsec, releasing gas into the 15 cc buffer volume between V1a and V2a. After V1a is closed, V2a is opened for 1 sec, releasing gas into the 60 cc buffer volume between V2a and V3a. By using two staging areas, the overall gas pressure can be brought down while allowing better control of the total gas mass. The release of gas through the two staging areas occurs several times until the required quantity of Xenon gas is in the second, 60 cc buffer volume. CO_2 is released from its reservoir into the 30cc buffer volume between V2b and V3b through an identical process.

Once each buffer volume has the requisite amount of gas, valves V3a and V3b are opened to release both volumes into the Mixing Vessel. Valves V3a and V3b are then closed and the gases are allowed to combine for 30 minutes in order to ensure complete mixing. After that, valve V4a can be opened to allow the gas to flow into Box C as needed.

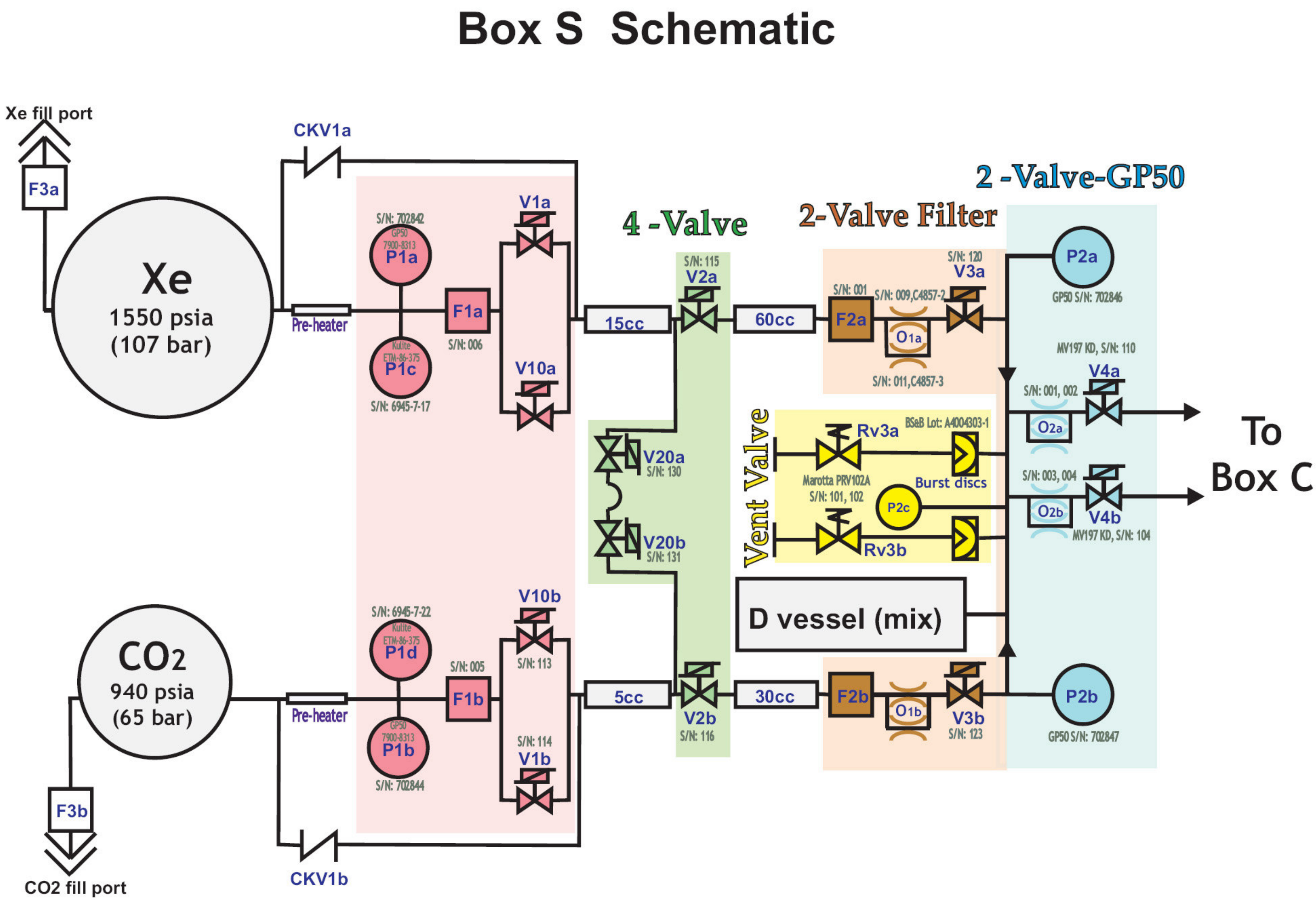

Figure 5.5.3-1 Box S TRD Gas Supply Detailed Schematic [PV pressures are at 77° F (25° C) with a nominal fill level]

The reservoirs are filled through the GSE fill ports and valves V17a and V17b. Valves V1a and V1b are closed and each tank is filled from a ground source. Temperature and pressure are then monitored for four hours. If performance is as desired, then the fill ports are capped and welded shut.

Several redundant valves have been included in the system to reduce the risk of mission failure, but are not required for safety:

- Valves V10a and V10b provide a secondary path from the reservoir to the first buffer volume in case of failure in valves V1a and V1b, respectively.
- Valves V20a and V20b provide a channel between the two reservoirs and the two sets of buffer volumes. If one of the valves V2a, V2b, V3a, or V3b were to fail closed, this allows each reservoir access to the buffer volumes on the opposite side.
- Flow restrictor O2b and valve V4b allow for a redundant path into Box C.

During launch and landing, all valves will be closed and the mixing vessel will be at 1.2 bar. All pressure and temperature sensors will be monitored from the ground as long as possible prior to launch. There are no planned go-no go launch restrictions for this monitored value. The sensors will also be monitored during all transfer and berthing operations.

Maximum design pressure for the gas reservoirs, the buffer volumes, and the associated piping through valves V3a and V3b have been determined through thermal analysis and all items have been shown to have sufficient structural margin. MDP of the mixing vessel and all plumbing between V3a/V3b and V4a/V4b is set at 300 psi based on the redundant burst disks shown in Figure 5.5.3-1. This hardware has also been shown to have adequate margin through structural analysis.

5.5.4 Box C Description

Box C, shown in Figure 5.5.4-1, contains the pumps for the primary TRD gas circuit. By causing the gas to flow continuously throughout each of the TRD’s 41 straw module, the gas is not able to separate into pockets and uniform properties are ensured. Box C is mounted on the USS-02 just above the main TRD Gas Supply, as shown in Figure 5.5.4-2.

Newly mixed gas from Box S arrives in Box C through valve V6a, where it merges with the gas coming out of the manifolds. This gas then flows through the Monitor Tube, shown in Figure 5.5.4-3 and 5.5.4-4. The Monitor Tube (also referred to as Calibration Tubes) analyze the pulse height spectrum from a 0.2 microCurie, Fe^{55} source to monitor the quality of the gas with a gain measurement. This source is contained within a thin layer of iron citrate deposited on the interior surface of the 6mm inner diameter of the Monitor Tube Structure. Radiation from the source is completely contained by the Monitor Tube's steel walls.

After leaving the tubes, the gas enters the canister, where two KNF Neuberger UNMP30 pumps provide the circulation through the system. These pumps operate in the open environment of the canister shown in Figure 5.5.4-1, with only one side of the pump connected directly to the plumbing. Only one pump is needed – a redundant pump is for mission success purposes. The gas then flows through an ultrasonic spirometer, which measures the CO_2 content in the gas flow and provides an independent check of the Xe/CO_2 ratio. The gas then flows back into the manifolds and re-enters the straw tubes.

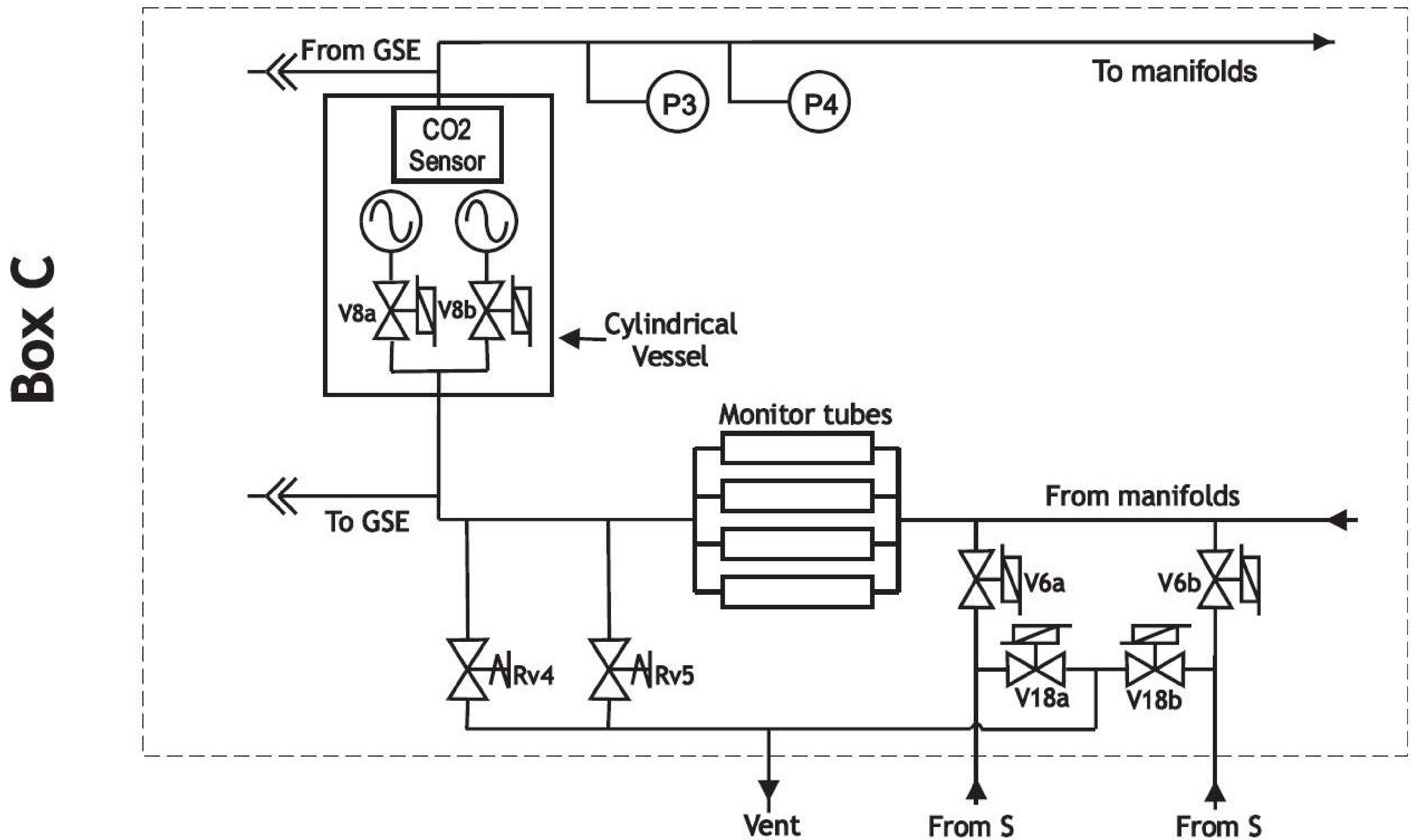

Figure 5.5.4-1 Box C TRD Gas Circulation System

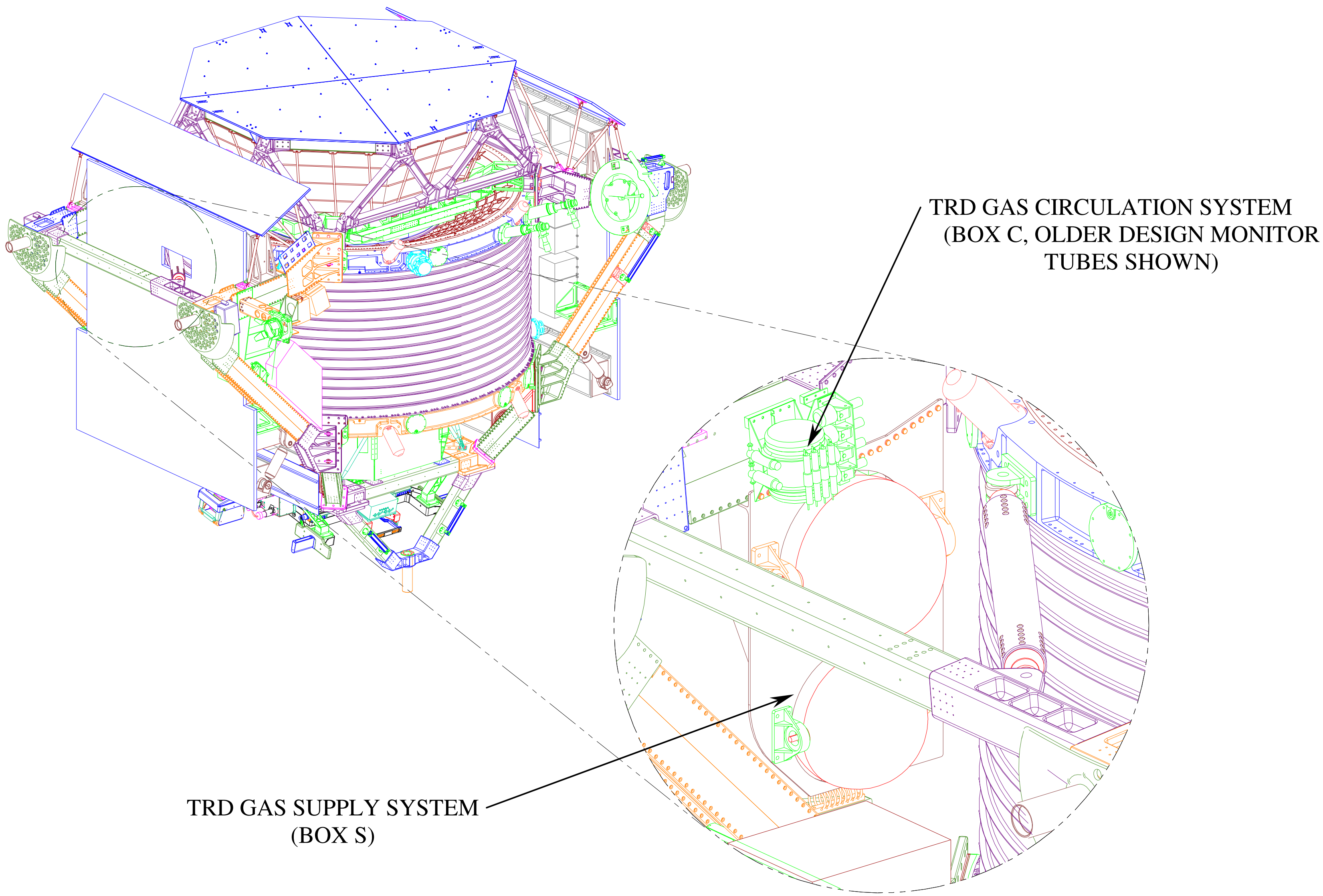

Figure 5.5.4-2 TRD Gas Circulation System (Box C) Mounted to the USS

As with Box S. several redundant valves have been included in the system to reduce the risk of mission failure, but are not required for safety:

- Valve V6b pairs with valve V4b in Box S and allows a redundant entry point for incoming gas.
- Valves V18a and V18b allow gas to be purged to space through a zero thrust vent in the case of incorrect gas mixing or contamination.

Note that valves V8a and V8b are only used to isolate the pumps during ground filling and draining operations.

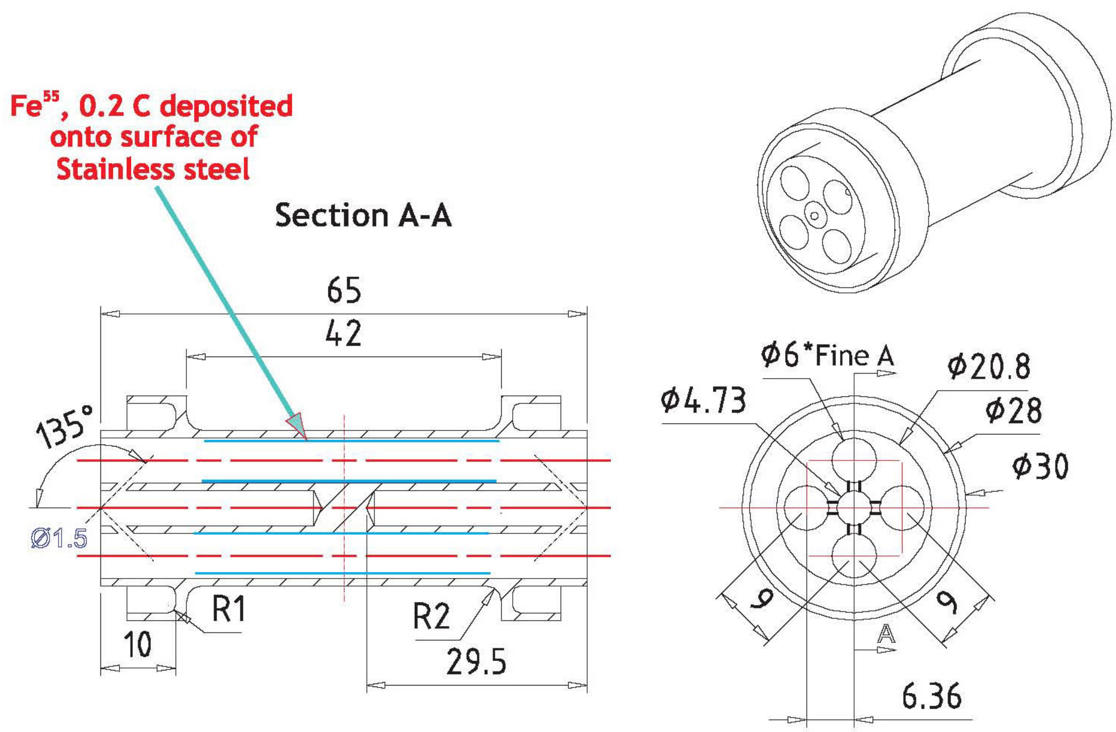

Figure 5.5.4-3 Calibration/Monitor Tube

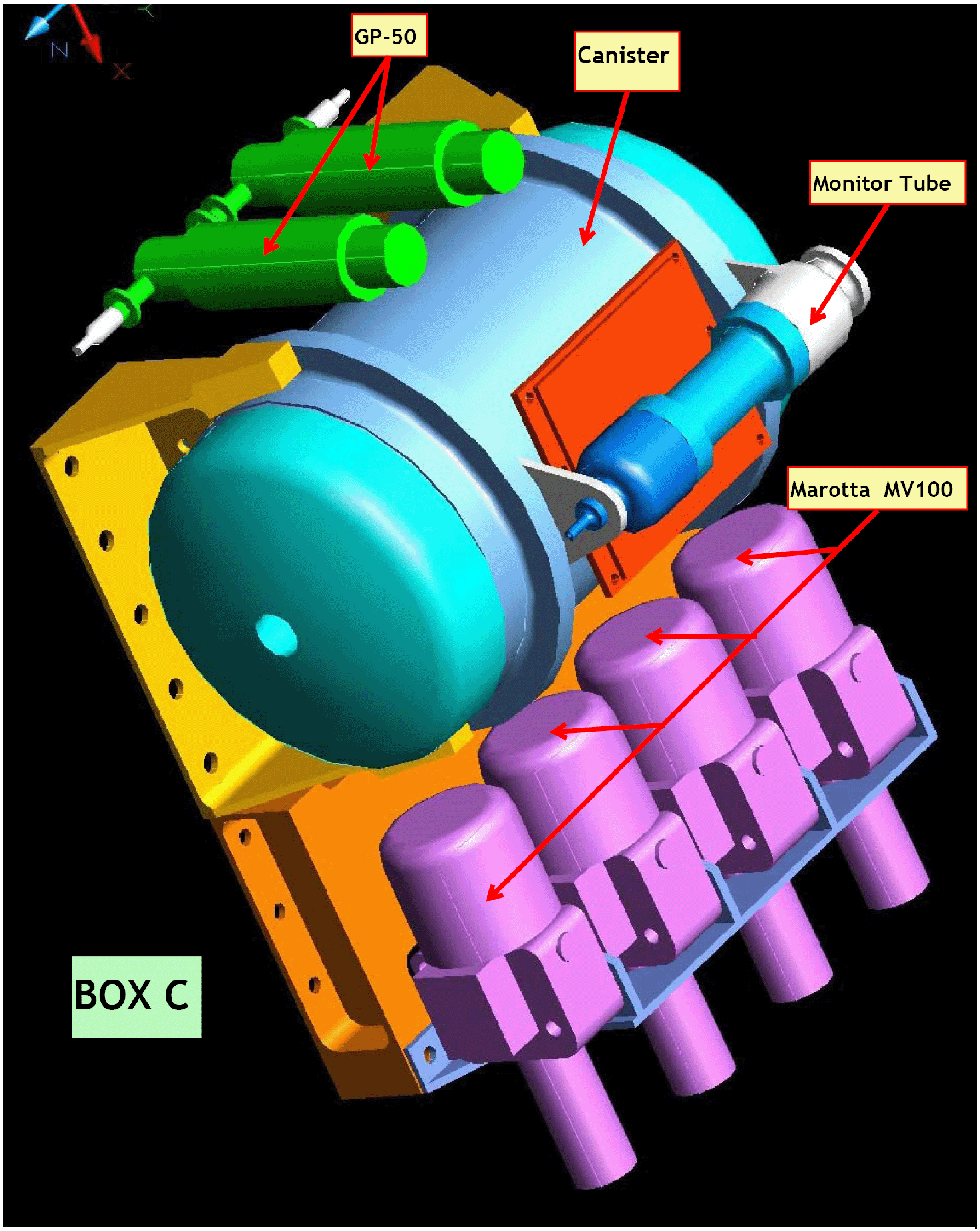

Figure 5.5.4-4 Location of TRD Calibration/Monitor Tube

5.5.5 Straw Tube Segments

From Box C, 3 mm stainless steel gas lines run to the top rim of the TRD, where input and output manifolds are located. The 5248 tubes of the TRD are grouped into 41 separate segments, each separately attached to input and output manifolds (Figure 5.5.5-1). Each segment is small enough so as not to be considered a pressure vessel (1 bar×7 liters=0.7 kJ). Each manifold is connected to the 41 TRD segments via pressure controlled isolation valves. 0.06 inch (1.6 mm) steel tubing runs from the isolation valves to the segment inputs and outputs, where it is joined to the straws via RWTH Aachen designed special connectors. Where other connections need to be made, Cajon VCR fittings are used. Figure 5.5.5-2 shows the locations of the gas manifolds and the input and output connections to the straw modules (one of 41 segments shown).

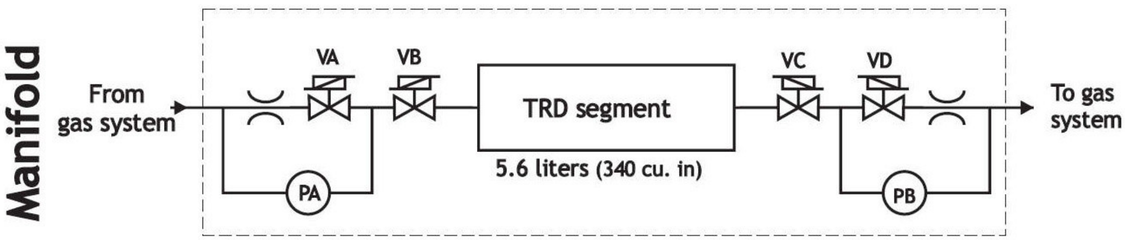

Figure 5.5.5-1 One of 41 TRD Straw Tube Segments

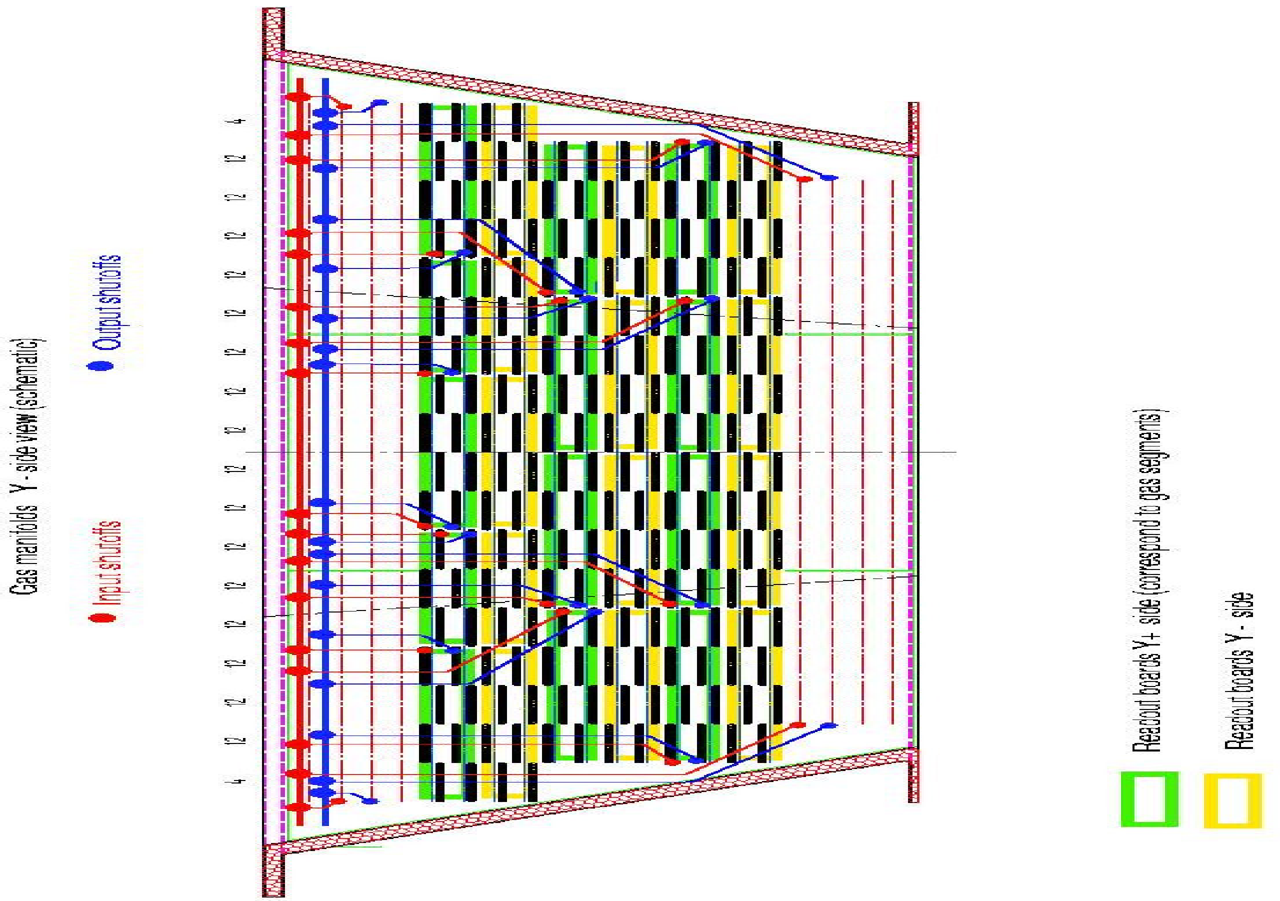

Figure 5.5.5-2 Gas Manifold Connections to TRD Segments

The isolation system is designed to protect the TRD against gas loss in order to maximize efficiency. Leakage of the Xe/CO_2 gas cannot produce a safety hazard, but can cause the gas supply to be used at a faster rate than anticipated and reduce the operational life of the TRD. The system works in two modes. In case of a sudden pressure drop in a segment, the control computer will close all four valves leading to the segment automatically to prevent further gas loss. In case of an increase in gas consumption, or as a periodic check, the computer will close all four valves and monitor the pressure. This will be used to detect slow leaks. Failure of any of the shutoff valves or pressure sensors cannot cause MDP to be exceeded.

The shutoff valve/pressure sensor assembly will be potted inside a magnetic shielding box to preclude any leak from the gas system volume. The isolation valves will be Burkert Type 6123 2/2 Way Flipper Valves. Closed, they hold 43.6 psi (3 bar) in either direction and have been leak tested to better than 0.1 ml/day loss, 14.5 psi (1 bar) to vacuum through a closed valve. They can be flipped from open to closed and vice-versa by a 12V, 100 μsec pulse, and otherwise consume no power. They are located near the top flange of the TRD in a region of low magnetic field. The pressure sensors are Honeywell type 24PC.

5.5.6 Monitoring and Control

The electronics that control the gas system will be located in the UG-crate. This crate will contain a Universal Slow Control Module (USCM) computer that will manage the monitoring and control tasks, as well as maintain communication with the AMS-02 Main DAQ Computer (JMDC). The USCM will be provided with interface electronics to the various gas transducers and actuators scattered throughout the gas system. The USCM and interface electronics will perform the following tasks:

1. Close or open emergency isolation valves in the manifolds.
2. Provide housekeeping data (temperature of valves, pressure vessels, etc.)
3. Store calibration constants.
4. Condition and perform analog to digital conversion for over 100 pressure sensors and approximately 500 temperature sensors distributed around the TRD and gas system.

5. Control two recirculation pumps.
6. Provide logic control for approximately 200 gas valves.
7. Provide HV for the calibration tubes in Box C.
8. The interface electronics will provide the power electronics to drive valves, etc.
9. Read out digital signals from the gas analyzer (spirometer) and calibration tube MCA.
10. Have control logic to switch the gas system to "Safe Mode" (for mission success) in case of communication failure.

The USCM, interface electronics, and calibration tubes are doubled to provide single fault tolerance for mission success. The USCM does not require or use batteries. If there is a power failure, the pumps stop, and all the Marotta valves close (they require power and special authorization to open). This ensures that the Xe and CO_2 gas tanks are sealed, and that no gas is transferred, either within Box S (e.g. to the mixing tank or other sealed volumes), or from Box S to Box C and the rest of the gas system. All mechanical safety release valves, for overpressure, remain operational. All of the flipper valves, which are used to isolate individual sectors of the gas system in case of leak, and to choose which pump is in-line with the overall gas circuit, remain in whatever state they were when power went off. This means that, on-orbit, if there is a leak which develops in the TRD when power is off, the worst that would happen is that we would lose (slowly, if the leak is in a single sector) the approximately 230 liters of gas in the TRD, which is small compared to the 10,000 liters of gas in the Xe and CO_2 tanks. Any sector previously isolated because of a leak would remain isolated. On the ground, a leak with power off would slowly contaminate the gas in the TRD with air so that it would not work well when power was switched on again, but would have no safety impact.

The TRD HV system consists of HV generation cards (UHVG) with 6 each located in the two U-crates controlled by the crate interface cards (JINF). Each UHVG card drives 7 HV lines with twofold internal redundancy to provide single fault tolerance for mission success. Each line is connected via shielded HV cabling to a HV distribution board (UHVD) mounted on the octagon in the vicinity of the readout cards to distribute the HV to 4 modules (64 tubes). The schematic of the HV system is shown in Figures 5.5.6-1 and 5.5.6-2. Each unit provides +1600V (control range: 700-1750V) with current limited to <100 microamps.

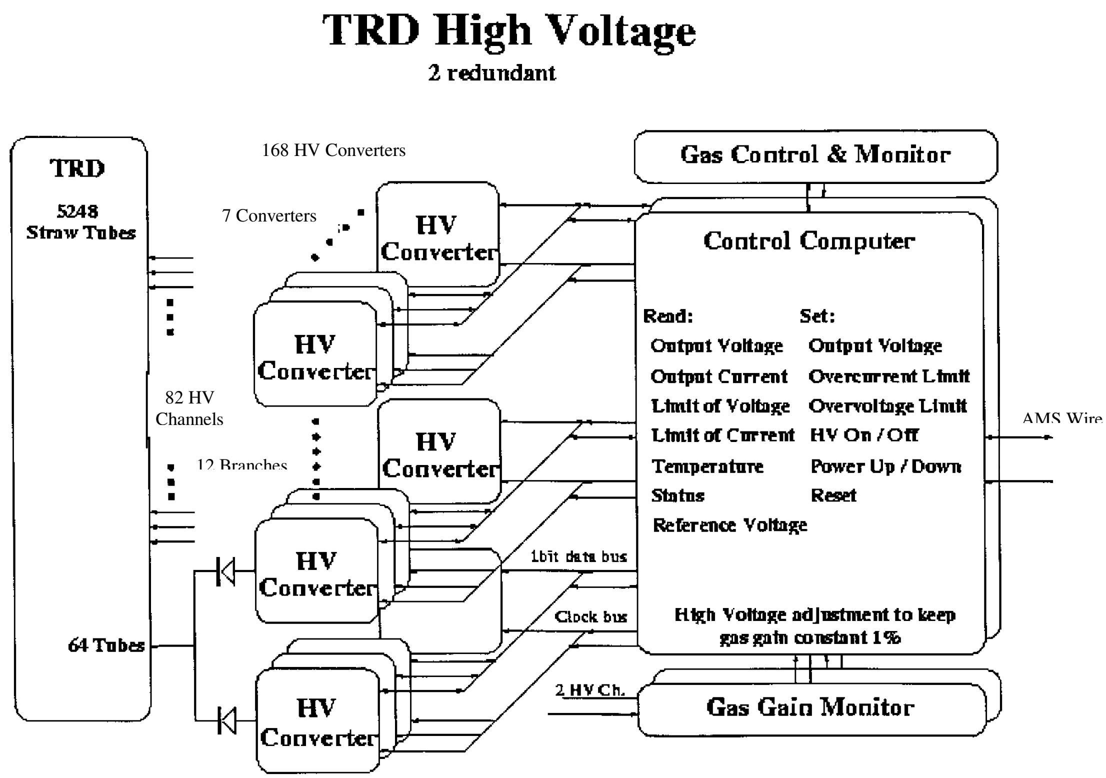

Figure 5.5.6-1 TRD High Voltage System

High Voltage Converter

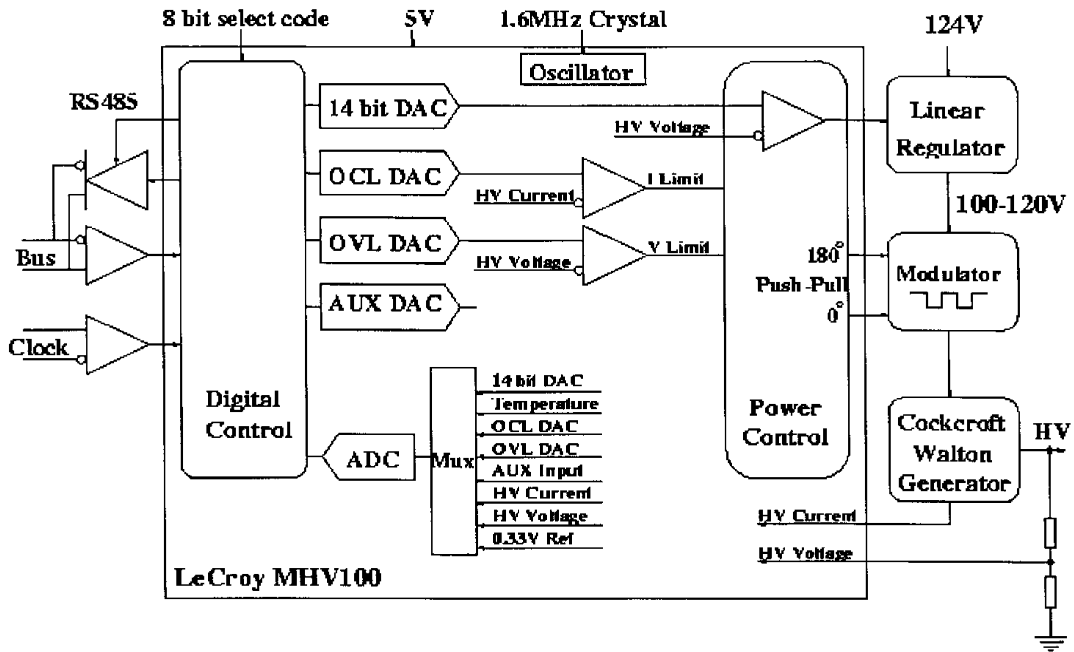

Figure 5.5.6-2 High Voltage Converter